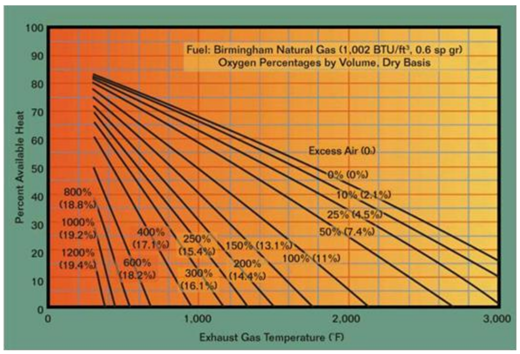
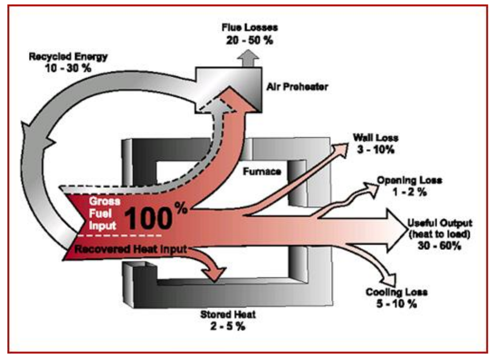
Calculate Available Heat for Natural Gas Fuel For Industrial Heating Equipment and Boilers





Prepared for California Energy Commission (CEC)

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(A Sempra Energy Utility)

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Executive Summary

This calculator tool is used to calculate available heat for natural gas and other gaseous fuels that are primarily used by California industries. The available heat is defined as the amount of heat remaining in heating equipment (i.e. furnace, oven, boiler, heater, kiln etc.) after the heat contained within flue gasses and other losses are subtracted from the total heat supplied to the heating equipment. The heat that remains in the furnace is directly applied to the process. The term available heat is useful in preparing a heat balance for process equipment such as furnaces or boilers. For most commonly used heating systems, the available heat depends on the following main parameters:

- Composition of fuel
- Exhaust gas temperature
- Oxygen (or excess air) in exhaust gases
- Combustion air temperature
- Fuel temperature

This calculator allows the user to give all of the above parameters as input parameters. The calculator results are given in terms of percent available heat for the given fuel at the user defined operating conditions.

For many energy saving measures, the calculation of available heat is required to reliably estimate energy savings potential. The available heat calculator is considered an essential part of many calculators offered in a series of calculators offered by the California Energy Commission (CEC) web site. Results obtained by use of this calculator have been verified by comparing them with commonly used references (1 to 3) in process heating industry. The results are within 5% accuracy and much closer for most commonly used exhaust gas temperatures between 400 °F and 2000 °F.

Note to the user of this calculator tool

Use of this tool requires knowledge of combustion and operation of heating systems such as a furnace, oven, heater, boiler, kiln, dryer etc. The user is referred to several training programs and references quoted at the end of his document for further information on the available resources for getting trainings that would provide additional knowledge for the subject matters discussed in this document.

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LIST OF EXHIBITS

1. Description of the subject area

This technical guide describes a calculator tool that will allow a user calculate available heat for gaseous fuel such as natural gas used by California industries. The calculator also gives higher heating value of the fuel. This tool is intended to be used for combustion of gaseous fuels used in commonly used heating systems such as boilers, furnaces, ovens, heaters, kilns, etc.

The available heat calculation is based on calculation of amount of combustion products produced by the complete combustion of the gaseous components of a given fuel compared to the amount of heat contained within the flue gas. The calculations allow for use of excess air used in combustion, use of preheated combustion air, sensible heat, and latent heat of water vapor produced by combustion of hydrocarbon fuels. Heating value calculations are based on the standard higher heating value of the fuel components. In almost all cases, the fuel is introduced at close to ambient temperature and is therefore assumed that the fuel is at ambient temperature.

A brief summary of the important parameters follows:

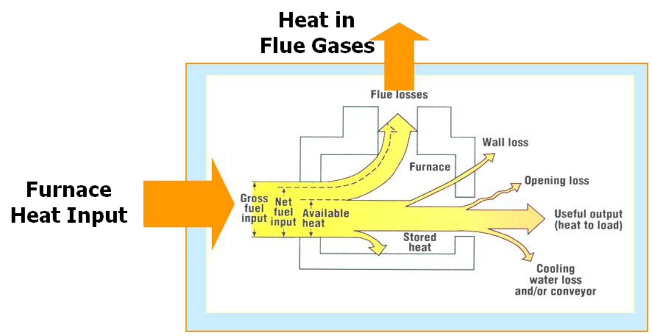
- **Fuel Gas Composition** – The fuel gas composition with components described in a alter section.
- **Exhaust or Flue Gas Temperature** - Temperature of the flue (stack) gases exiting the process or heating equipment.
- **Oxygen Concentration in Flue Gas** – Percentage of oxygen in the flue gas measured on a dry basis.
- **Combustion Air Temperature** – The temperature of the combustion air that is the air mixed with fuel in the burner.

2. Discussion on the technical approach and the calculations

Available heat is defined as the difference between the heat entering a heating system and the heat discharged from the flue gas. The available heat represents the amount of heat that remains within the heating system as a fraction of the heat input. A heating system designer's goal is to maximize available heat while meeting the process requirements. Available heat is sometime, erroneously, is referred to as "efficiency" or the "combustion efficiency" of a heating system. Exhibit 1 shows a simple representation of available heat and an accepted definition as percent available heat for a system.

A higher percentage of available heat means more of the heat input remains in the heating system and results in reduced losses through the flue gases. This results in better performance for the system. The value of available heat is independent of the heating system design as long as the following parameters listed below are known:

- **Fuel composition** – The initial fuel composition directly affects the ultimate composition of combustion products and the amount of heat released into heating system. In general, with all other conditions remaining the same, flues containing higher carbon monoxide and hydrogen would have lower available heat.



Available Heat = (Furnace Heat Input – Heat in flue gases)

$$\textbf{Percent Available Heat} = \left(\frac{\textbf{(Furnace Heat Input – Heat in flue gases)}}{\textbf{Furnace Heat Input}} \right)$$

Exhibit 1: Definition of available heat

- **Flue gas temperature** – Higher flue gas temperature increase the heat content of flue gases and lowers the amount of heat remaining in the heating system. This would result in lower available heat.
- **Percent oxygen (O_2) in exhaust gases** – The amount of excess air in flue gases is represented by amount of O_2 in flue gases. Higher O_2 value indicates higher excess air and a greater amount of heat contained within the flue gases. This results in a lower available heat.
- **Combustion air temperature used for the burners** – Raised combustion air temperatures increases the available heat compared to combustion air at ambient temperature.
- **Fuel temperature** – Use of preheated fuel increases value of available heat. In almost all cases, it is recommended that high heating value fuels such as natural gas should not be preheated. In this calculator we have assumed that fuel temperature is at ambient temperature.
- **Other factors** – Several other factors unrelated to fuel combustion in a heating process can affect available heat for a fuel. The discharge of water vapor, water, or other gases such as carbon dioxide into a heating system will reduce value of available heat. In such cases it is necessary to conduct detail flue gas analysis using special instruments to measure the composition and total heat content of the flue gases.

In the case of this calculator, the available heat for a fuel is based on an assumption that neither additional gasses, liquids or solid particles are discharged from the product being processed nor injected into a heating system. All commonly used literature, handbooks, or similar sources give available heat with the same assumption stated.

For this calculator, the fuel gas composition is expressed in terms of the components listed in Exhibit 2. Exhibit 2 also shows the chemical composition of a “typical” natural gas used in California. Note that hydrocarbons higher than C_4H_{10} series are accounted as C_4H_{10}. This assumption does not affect the results since most commonly used natural gas used in California contains minute amount of such hydrocarbons and error in the results would be very small.

Fuel Gas Analysis (See note below)		
Gas composition	**By volume**	**Adjusted by volume**
CH4	**94.10%**	**94.241%**
C2H6	**2.40%**	**2.404%**
N2 and other inert	**1.41%**	**1.412%**
H2	**0.03%**	**0.030%**
C3H8	**0.49%**	**0.491%**
C4H10 + CnH2n	**0.29%**	**0.290%**
H2O	**0.00%**	**0.000%**
CO	**0.42%**	**0.421%**
CO2	**0.71%**	**0.711%**
SO2	**0.00%**	**0.000%**
O2	**0.00%**	**0.000%**
Total of fuel components	**99.85%**	**100.000%**
Difference	**0.15%**	**0.00%**
Note: The fuel gas composition is in volume %. The higher hydrocarbons in fuel are treated as same as C4H10 and all other inert gases are treated as N2.		

Exhibit 2**:** Typical fuel (natural gas) components and analysis

First step is to calculate products of combustion by using standard equations taken from reference 1 and given below.

Exhibits 3 and 4 are then used to determine the values of specific heat of the flue gas components such as N_2, CO_2, H_2O, etc. These values are used to calculate total heat content of flue gases.

Where

= Total heat content of the respective flue gas component. Expressed in

= Mass of the respective flue gas component. Expressed in

= The specific heat of the respective flue gas component. Expressed in

= Flue gas temperature expressed in

= Vaporizing temperature of water at its partial pressure in the flue gases. Expressed in

= The reference temperature. Assumed to be 60

= Latent heat of vaporization for water at its partial pressure in flue gases expressed in

Gas	Temp (F)	Temp ®	Cp Btu/(#mole.F)	Mol wt	Cp Btu/(#F)	Sp. Vol SCF/#	Sp. Wt #/SCF	Sp. Gravity wrt Air @stp	Cp Btu/SCF	Mean CP Btu/SCF
Oxygen	60	520	6.915	32	0.216	11.819	0.0846	1.1089	0.0183	0.019799
Oxygen	1000	1460	8.061	32	0.252	11.819	0.0846	1.1089	0.0213	
Nitrogen	60	520	6.754	28	0.241	13.507	0.0740	0.9703	0.0179	0.01897
Nitrogen	1000	1460	7.595	28	0.271	13.507	0.0740	0.9703	0.0201	
Carbon Monoxide	60	520	7.090	28	0.253	13.507	0.0740	0.9703	0.0187	0.019565
Carbon Monoxide	1000	1460	7.709	28	0.275	13.507	0.0740	0.9703	0.0204	
Hydrogen	60	520	6.938	2	3.469	189.100	0.0053	0.0693	0.0183	0.018595
Hydrogen	1000	1460	7.127	2	3.564	189.100	0.0053	0.0693	0.0188	
Water vapor (H2O)	60	520	8.103	18	0.450	21.011	0.0476	0.6238	0.0214	0.023104
Water vapor (H2O)	1000	1460	9.373	18	0.521	21.011	0.0476	0.6238	0.0248	
Carbon Dioxide	60	520	8.857	44	0.201	8.595	0.1163	1.5248	0.0234	0.028088
Carbon Dioxide	1000	1460	12.389	44	0.282	8.595	0.1163	1.5248	0.0328	
Methane - CH4	60	520	10.350	16	0.647	23.638	0.0423	0.5545	0.0274	0.041994
Methane - CH5	1000	1460	21.414	16	1.338	23.638	0.0423	0.5545	0.0566	
Ethylene C2H4	60	520	8.352	28	0.298	13.507	0.0740	0.9703	0.0221	0.031244
Ethylene C2H5	1000	1460	15.280	28	0.546	13.507	0.0740	0.9703	0.0404	
Ethane C2H6	60	520	12.547	30	0.418	12.607	0.0793	1.0396	0.0332	0.053507
Ethane C2H7	1000	1460	27.926	30	0.931	12.607	0.0793	1.0396	0.0738	

Source - Gas Engineers Handbook

Exhibit 3: Thermal properties for gasses

For Air at 60 F., 80% Humidity					
Composition of gas mixture	% Vol	% mass	Mean CP Btu/scf	Cp-60 F	Cp 1000F
Oxygen	20.70	23.20	0.0198	0.0183	0.021
Carbon Dioxide	0.00	0.00	0.028	0.0234	0.033
Nitrogen & Other	78.30	75.80	0.019	0.0179	0.020
Water vapor	1.00	1.00	0.023	0.0214	0.025
Total	100.00				
Mean value			0.019183367	0.017982	0.020384837

Exhibit 4: Thermal properties for gasses, cont.

The total heat content of flue gases is the sum of the heat content of all flue gas components i.e. , and .

The amount of available heat is calculated using following equation:

Where

is the total heat input into the furnace. Expressed in and is calculated using

is the total heat in flue gases. Expressed in

is the higher heating value of fuel. Expressed in

is total heat content of combustion air. Expressed in and is calculated using

is the specific heat of air. Expressed in

is the total mass of air heated within the unit and includes excess air. Expressed in

3. Instruction on use of the calculator

The following list summarizes the required user inputs. The user should collect this information before using this calculator tool:

- Company name, plant location and address
- Customer name and contact information
- Heating equipment description (where the energy-saving measure is applied)
- Equipment type (furnace, oven, kiln, heater, boiler)
- Equipment use (e.g., textile drying, aluminum melting, food processing)
- Fuel composition as used in terms of volume percentages including moisture
- Oxygen in flue gas (%, dry basis)
- Combustion air temperature (°F)
- Exhaust or flue gas temperature (°F)

Note: Some of this information may be optional for the web-based calculators due to users' concerns about privacy.

The calculator gives following results:

- Heating value (higher or gross) in terms of Btu per std. cu. ft.
- Available heat (% of higher heating value)
- Percentage oxygen in exhaust (flue) gases
- Excess air in flue gases (%)
- Available heat for the furnace (%)

The excess air reduction calculator requires the following input parameters describing the heating process in order to estimate the savings. **Exhibit 5** shows the user information section and **Exhibit 6** shows the calculator section.

The first section requires information about the user, equipment, and process.

Line 1 – <u>Name of the company</u>

Line 2 – <u>Name or known designation such as "main plant" or "secondary plant" if applicable</u>

Line 3 – <u>Plant address</u>

Line 4 – <u>Contact name</u> – This individual is main contact and is responsible for collecting and providing the required information.

Calculate Available Heat						
1	Company name	ABC Corporation				
2	Plant name or designation	LA Plant				
3	Plant address	12345 Main Street, Gabriel, CA 90878				
4	Contact name	Bob Smith				
5	Contact address	54321 First Street, North Warren, CA 90878				
6	Contact phone number and e-mail	Phone:	916-756-9923		E-mail:	b.smith@abccorp.com
7	Date (format mm/date/year)	May 12, 2010				
Heating equipment description (where the energy saving measure is applied)						
8	Equipment type (e.g. furnace, oven, kiln, heater, boiler)			Furnace		
9	Equipment use (e.g., textile drying, aluminum melting)			Metal heating		
10	Other comments if any	The furnace was rebuilt recently.				

Exhibit 5**:** Required information for calculator user

Line 5 – Contact address

Line 6 – Contact phone number and e-mail – Information to be used for all future communications with customer

Line 7 – Date

Line 8 – Equipment type – This can be an oven, furnace, boiler, heater, etc. This is the heating equipment where data is collected and the given energy saving measure is to be applied.

Line 9 – Equipment use – This can be name of the process such as drying, melting, water heating, etc.

Line 10 – Other comments

The second section of the calculator requires data input for the gaseous fuel used and certain operating parameters.

Lines 11 to 21– Fuel Composition – These cells require user input for the fuel components and their percentages as reported from the fuel analysis. The analysis should be reported as volume percentages. This is given in the first column “by Volume”. The second column tiled as “Adjusted by volume” and it represents normalized values of volume percentages so that the total percentage of all components is 100%.

Line 22 – Total of Fuel Components – This is calculated sum of all percentages entered in lines 11 to 21 under the heading “By Volume”. This value is adjusted to 100% in the second column by “normalizing” the values for each of the components.

Line 23 – Difference – This is a calculated value difference between the total given in “By volume” and 100%.

Line 24 – Combustion air temperature (°F) – The user gives temperature of combustion air entering the burners. In many cases it is not possible to get the exact air temperature at the burner. A common workaround is to use the temperature of air entering the combustion air blower or the ambient temperature around the air blower. For a case where preheated combustion air is used it is necessary to use combustion air temperature at the burner or at the exit of the air preheating equipment such as a recuperator, regenerator or regenerative burners.

Line 25 – <u>% Oxygen (O2) in Combustion Air</u> – This value should remain unchanged from 20.9 unless the combustion air is enriched with oxygen prior to combustion.

Fuel Gas Analysis (See note below)				
	Gas composition	**By volume**	**Adjusted by volume**	**Comment**
11	CH_4	96.36%	96.485%	
12	C_2H_6	1.44%	1.442%	
13	N_2 and other inert	0.32%	0.320%	
14	H_2	0.00%	0.000%	
15	C_3H_8	0.31%	0.310%	
16	$C_4H_{10} + C_nH_{2n}$	0.06%	0.060%	
17	H_2O	0.00%	0.000%	
18	CO	0.00%	0.000%	
19	CO_2	1.38%	1.382%	
20	SO_2	0.00%	0.000%	
21	O_2	0.00%	0.000%	
22	**Total of fuel components**	**99.87%**	**100.000%**	
23	**Difference**	0.13%	0.00%	

Note: The fuel gas composition is in volume %. The higher hydrocarbons in fuel are treated as same as C_4H_{10} and all other inert gases are treated as N_2.

24	Combustion air temperature (°F)	600
25	% Oxygen (O_2) in COMBUSTION AIR	20.9
26	% Oxygen (O_2) in flue gases	3.8
27	Calculated percentage excess air used	19.8
29	Exhaust (flue) gas temperature (°F)	1450
30	**Available Heat: (% of higher heating value of fuel)**	**64.38%**

Click here for detailed Results

Exhibit 6: Example of calculator inputs and results

Line 26 – <u>Percent oxygen (O_2) in flue gases (%)</u> – This is obtained from flue gas analysis using commonly available combustion or flue gas analyzers. These meters give the flue gas analysis on dry basis. The sample for the gas analysis should be taken when the furnace is operating at normal operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. It is necessary to make sure that the flue gases are NOT mixed with cold air before the gas is measured. Care should be taken to locate the sampling probe in the middle of the stack or area from where the flue gases are discharged. Collecting the sample at the top of the stack or very close to the wall of the discharge duct can give erroneous reading. It is also necessary to make sure that there is no air leakage through the sampling port when the sampling probe is inserted in the stack or sampling location.

Line 27 – Percent Excess Air (%) – This is a calculated value of excess air present in the flue gases. It is calculated assuming natural gas is used as fuel. However, this result is considered valid for different compositions of natural gas and for most hydrocarbon fuels. Note that this is a first approximation value that is used to calculate the expected O2 value for the given fuel. The calculated value is reported in Results section - Line 31 of this calculator.

Note: There is no line 28

Line 29 – Exhaust (flue) Gas Temperature (°F) – Give exhaust or flue gas temperature measured as close to the exit of the heating system (i.e. furnace, boiler, oven) as possible. The flue gas temperature should be taken when the heating equipment is operating at normal operating conditions. It is necessary to make sure that the flue gases are NOT mixed with cold air before the temperature is measured. Care should be taken to locate the thermocouple or temperature measurement sensor in the middle of the stack or area from where the flue gases are discharged. Measuring the temperature at the top of the stack or very close to the wall of the discharge duct can give erroneous reading. Note that in almost all cases the flue gas temperature does not change by any significant value with the use of preheated combustion air, since the heating equipment zone temperatures are controlled to meet the required process conditions.

Line 30 – Available Heat (% of higher Heating Value of Fuel) – This is calculated value and it is based on higher heating value of the given fuel.

4. References and Resources

1. *North American Combustion Handbook,* Third Edition, 1986. Published by North American Mfg. Company, Cleveland, OH.
2. *Combustion Technology Manual*, Fifth Edition, 1994. Published by Industrial Heating Equipment Association, Cincinnati, OH.
3. *Industrial Furnaces,* Sixth Editio. Published by Wiley, John Wiley and Sons, Inc. NY ,
4. *Improving Process Heating System Performance: A Sourcebook for Industry*, U.S. Department of Energy and Industrial Heating Equipment Association. Available online at

   http://www1.eere.energy.gov/industry/bestpractices/pdfs/process_heating_sourcebook2.pdf
5. *Tip sheets and Technical Briefs*, published by The U.S. Department of Energy. Available online at

   http://www1.eere.energy.gov/industry/utilities/steam_tools.html
6. *Unit Conversions, Emission Factors and Other Reference Data*, published by the U.S. EPA, November 2004. Available online at http://www.epa.gov/cpd/pdf/brochure.pdf
7. Training opportunities for process heating technology
   - The U. S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE) Office of Industrial Technologies (ITP) web site. http://www1.eere.energy.gov/industry/
   - Sempra Energy – Southern California Gas Company web site www.socalgas.com

California Energy Commission web site www.energy.ca.gov